Renewable and Sustainable Energy Reviews 15 (2011) 1491–1496

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Status and potentials of renewable energies in Yazd Province-Iran

A.A. Dehghan*

School of Mechanical Engineering, Yazd University, P.O. Box 89195-741, Yazd, Iran

ARTICLE INFO

Article history:
Received 8 September 2010
Accepted 4 November 2010
Available online 12 January 2011

Keywords:
Renewable energy potentials
Yazd Province
Iran

ABSTRACT

The present study attempts to review and discuss the status and potential of Yazd Province in utilizing renewable energy sources with a special focus on solar and wind energies. Solar insulation data reveals that the region has great potentials for harnessing solar energy and implementing the related promising available technologies. The province is experiencing power generation by a 12 kW off grid PV system for electrification of Dorbid village for many years. Besides, the biggest solar energy utilization project in the Middle East, the installation of 467 MW combined gas-steam-solar power plant is dedicated to the power generation of this province. According to the experimental work conducted, it is shown that utilizing other low cost solar technologies such as domestic solar water heaters and solar ponds are also reliable means of serving supplementary thermal energy demand of the region. The local wind data shows that the province can benefit wind energy for running small wind turbines or driving wind pumps for water irrigation purposes. The highly subsidized energy supplied by the government is a major barrier of renewable energy adoption. However, the desubsidazation plan, which is to be implemented to the energy commodities by the Iranian government, will inevitably brings the employment of renewable energy to a closer attention.

Contents

1. Introduction

Technological and industrial development resulted in improvement in standard of living and more energy demanding life. By current increase in energy consumption rates, energy supply will be a real challenge in a near future for the whole world and even for currently rich oil countries. The world energy production in 2000 and 2007 was 1.65 (ton oE) and 1.82 (ton oE) per capita respectively, indicating growth rate of 10.3 percent [1]. Therefore, many countries have paid high attention to utilize alternative sources of energy particularly the renewable ones to meet their growing energy demands and have taken actions in the development and application of renewable energy technologies for sustainable development. Moreover, the current environmental issues specially greenhouse gas emissions enhances these efforts.

Iran's "Energy Security" is based on oil as the primary source of energy. The energy production in the country in 2000 was 1.84 (ton oE) per capita which has been increased to 2.6 (ton oE) in 2007, showing 41% increase in energy production rate. According to the incremental rate, energy production is anticipated to reach around 4 (ton oE) per capita by 2020 due to the social and economical development, ecological improvement and promotion of life standard.

Iran benefits vast resources of fossil fuel in the form of oil or natural gas reserves in the region (18.2% of oil reserves and 30.5% of natural gas reserves in the Middle East). Energy consumption sectors in Iran enjoy energy utilization in the form oil, natural gas or electricity with highly subsidized prices for many years. For instance, subsidized natural gas price is 0.85 cents/m^3 while its real price is 6.60 cents/m^3. Electricity is also supplied to the household

* Corresponding author. Tel.: +98 351 812 2493; fax: +98 351 821 0699.
E-mail address: adehghan@yazduni.ac.ir

1364-0321/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2010.11.002

users, agricultural and industrial sectors with the average subsidized price of 1.65 cents/kWh while its real price is 7.36 cents/kWh [1]. So it is seen that natural gas and electricity are delivered with almost 13% and 29% of its real prices. The subsidized delivery of energy is the major barrier for renewable energy development and utilization. Moreover, lack of motivation and incentives among the energy users and inadequate advertisement and justification of renewable energy technologies by government circle and media limits the application of such green energy sources among the users. Recently the Iranian government has embarked a desubsidization plan to gradually lift the subsidies from both electricity and fossil fuel energy commodities which has been approved by the Iranian parliament. This will causes sharp rise on the energy prices and as a result on the production costs. Therefore, looking for and utilizing renewable energy sources and their related technologies in order to prevent rise in the production cost, promote social development and economical progress is an inevitable challenge in near future.

Iran is potentially one of the best regions for utilization of most alternative sources of renewable energies such as hydroelectric, solar, wind, geothermal and tidal. The potentials and share of alternative energies utilized for power generation in Iran is studied and discussed with a focus on the role of hydroelectric and wind energy sources in power production [2]. It was concluded that the utilization of such renewable energies for electricity generation in Iran is in its initial stages. It was also reported that in 2001, the share of renewable energies like; hydropower, wind and solar in electricity generation was around 8.9%. Present figure for 2008, show that share of hydropower in electricity generation is dropped to 2.6% while the share of solar and wind energies is 0.102% [1]. Although the government policy is to increase the share of hydropower production, the recent drops in the share is due to the drought in the country. The share of renewable energy in power generation shows a promising rise indicating a 36.9% increase from 2007 to 2008. Recently, the status of Middle East countries in utilizing different sources of energies is investigated and discussed in which the status of renewable energies in Iran with a focus on wind energy's potential is also highlighted [3].

The present paper attempts to explore the potentials of Yazd Province to harness and utilize different sources of renewable energies and the feasible ways of implementing their related technologies to secure the sustainable development of the region. Moreover, some academic researches, which are mostly carried out by regional institutions to explore and demonstrate the feasibility and applicability of such green energy sources, are reviewed and discussed. As some of the renewable energy types such as hydroelectric, geothermal and tidal energies have no potential and hence no applicability in the region, the status and feasibility of utilizing solar and wind energies is discussed. The aim is to promote the public awareness and inspire local government to devote more funds and efforts in the renewable energy utilization.

2. Yazd Province

Yazd Province has an area of 131,575 km^2 and is situated in the central part of Iranian plateau bounded by latitudes of 29–34N and longitudes of 52–56E (Fig. 1). Its population according to the latest census (2005) is around 990,000 in which about 80% are urban dwellers and the rest are living in rural areas. The province is in the arid regions and borders the main central desert of Iran. The annual precipitation is between 50 and 108 mm. The lowest temperature is $-20\,^{\circ}C$ at mountainous regions and the highest temperature may reach $47\,^{\circ}C$ during the day in summer. Fluctuations of temperature are too much in summer and winter, during the day and night, which is a unique feature of the region, normally causes



Fig. 1. Map of Iran.

great air movement and induces wind motion especially during the seasons of spring and summer. The province includes 10 cities named Abarkouh, Ardakan, Bafgh, Khatam, Maybod, Mehriz, Tabas, Sadough, Taft, and Yazd. Each city includes smaller towns and villages. The capital of Yazd Province is Yazd city with a population of about 523,000. It is almost an industrial city rich in textile and tile industries. Amidst the immense surrounding desert, Yazd preserved its old religion, traditions, and architecture. An outstanding feature of Yazd city is its traditional architectures.

3. Solar energy potentials

Being in the sun-belt, Yazd Province is ideal location to benefit the advantages of solar energy utilization and adoption of its related technologies (Fig. 2). The daily average of solar insolation in Yazd Province is between 4.5 and 5.5 kWh/m^2 with about 3200 sunshine hours in a year [2]. In an analytical study, the total radiation received by a horizontal surface in Yazd Province during a year is reported to be around 6750 MJ/m^2 [4]. Undoubtedly, this region has large potential in harnessing solar energy for electricity generation, heat production, water pumping, etc. Solar photovoltaic (SPV) is one of the first technologies adopted for meeting the basic energy demand in rural areas with no access to the electrical grid. The assessment of the SPV based decentralized electrification for rural areas are comprehensively reviewed by reference [5]. The first solar energy utilization in Yazd Province dates back to 1999 when a 5 kW PV power generation was installed in Dorbid, a remote located village in north-east of the province. The system was installed to assist the low voltage grid connected to the village. Dorbid PV system was later upgraded to 12 kW. Fig. 3 shows the power generation from Dorbid PV system between 2001 and 2008.

Although the Dorbid project is the only PV based power utilization in Yazd, the potentials of this province in PV based power generation is great. Solar PV power systems can be classified as standalone, PV hybrid and grid connected. Standalone PV systems may be utilized for street lightening, power generation for the remotely located villages and for solar powered pumps. Iran is a developing country and has got many dispersed villages and remote regions. Thus the power supply by electrical national grid to every inhabited location is not economically feasible. This proves true for Yazd Province with vast deserted area and remotely located villages with less than 20 families. During last two years, Yazd Province encountered severe drought with annual precipitation of

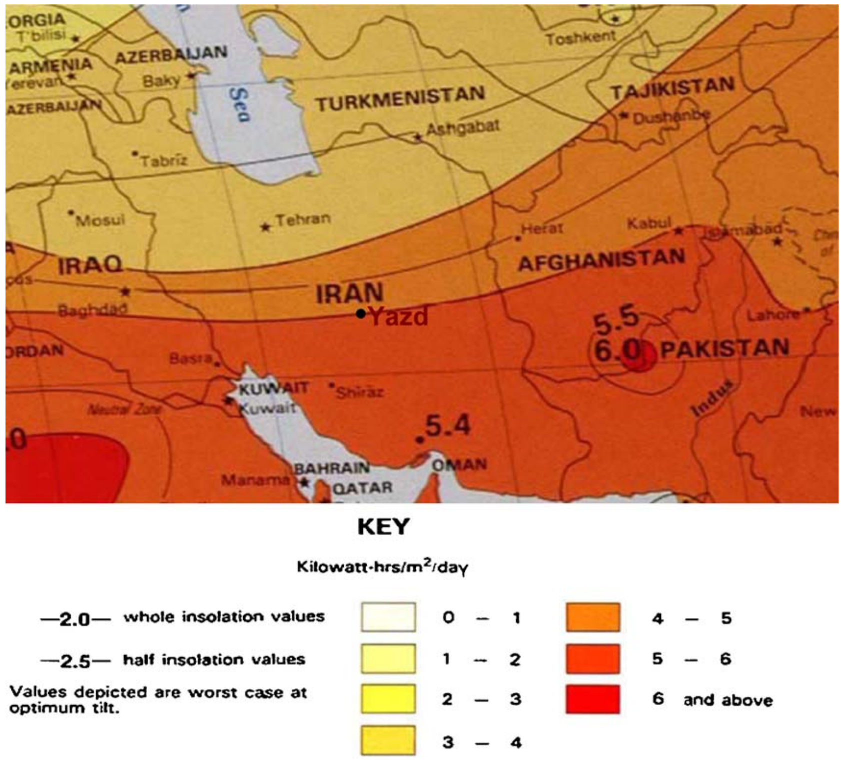


Fig. 2. Solar insulation map of Iran [6].

around 60 mm. Therefore, farmers started digging wells in their lands, farms or fruit gardens in order to access underground water resources for irrigation. As the access to the national gridlines is limited in farmlands, they usually use petrol power generators to drives pumps. It is shown that the solar powered pumps present a viable solution for irrigating lands in rural areas with hard national grid accessibility [7]. Therefore, it is the responsibility of the local government to provide solar PV water pumping system to the farmers of the province with subsidies prices as an alternative for the conventional petrol power generators. This helps the farmer to overcome the drought and also sustain the micro economy of the region and also reduce the utilization of fossil fuel.

Due to the remarkable sunshine hours in this province, the biggest solar energy utilization project for power generation in Iran and even in the Middle East was devoted to Yazd Province by the Ministry of Energy. The project was 467 MW Integrated Solar Combined Power Station (ISCPS). The power station is the world's first combined cycle power plant using solar power and natural gas and stands as the eight largest solar power plants in the world. It consists of two 159 MW gas turbine units, one 132 MW steam power plant and a solar steam generation unit with the capacity of 17 MW. The outlet hot gases from two gas turbine units are directed to the Heat Recovery Steam Generator (HRSG) of the bottoming steam turbine cycle. The energy captured from the solar unit is due to be utilized in the preheater of HRSG. The gas and steam turbine units are now under operation, but the solar farm is still under construction with 70% completeness and is expected to join to the gas-steam turbine units in 2011. The solar unit utilizes solar farms encompassing several arrays of parabolic trough collectors. The working fluid in the solar farm is oil which is fed to a steam generator heat exchanger. The steam generated in the heat exchanger is directed towards the HRSG and mixes with the rest of the steam generated in the HRSG. The solar farm unit in such combined systems acts as a supplementary firing system employed in conventional combined power plants. Annexing the solar farm to the gas-steam combined cycle not only boosts the thermal efficiency of the hole power plant but also helps the system to meet the peak electrical demand specially in hot summer days when the gas turbine units encounter with power loss due to high inlet air temperature to their compressors.

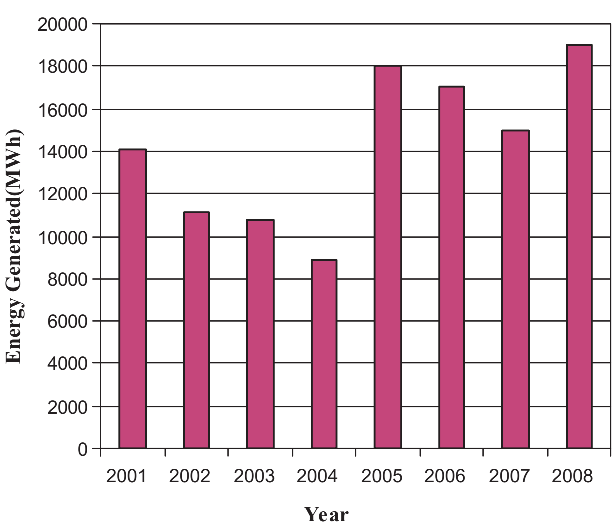


Fig. 3. Power generated by Dorbid PV system from 2001 till 2008.

Domestic Solar Water Heating Systems (DSWHS) are other alternatives for harnessing solar energy in the province. These systems are employed to absorb and store the solar energy during the daytime and deliver it on demand. A DSWHS consists of a flat plate solar collector, a thermal reservoir, an auxiliary heater and a series of junction tubes. The working fluid, usually water, absorbs the solar energy through the collector and delivers it to the storage tank for later use. The technology of DSWHS is quite mature and a number of private companies are actively involved in production of such systems. In Iran, both the Ministry of Energy and Ministry

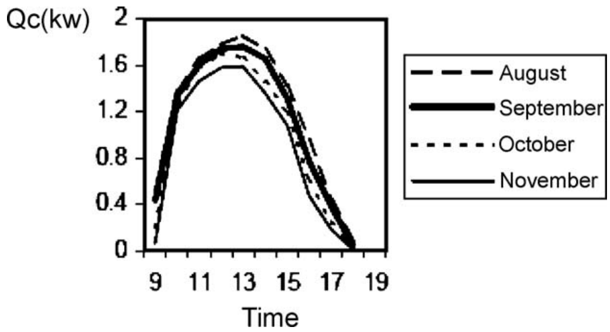


Fig. 4. The daily variation of net rate of thermal energy delivered by the collector loop.

of Oil are involving in distributing the DSWHS among the potential users. From 2000 to 2002, the Ministry of Energy distributed 1041 such systems in Yazd, Isfahan, Khorasan and Sistan provinces with subsidized prices to promote its utilization. It was targeted to distribute 215000 such systems till 2008. In Yazd Province, several houses, schools and government buildings are now equipped with DSHWS to provide their hot water demands. A number of researches have been conducted in Yazd University to evaluate the thermal performance of such systems. Among them, an experimental study conducted for thermal performance analysis of a DSWHS in Yazd climate can be mentioned [8]. The study was conducted by installing a DSWHS with a vertical storage tank on rooftop of a four person family house located in Yazd city. Its thermal performance was closely monitored by carefully measuring the temperature distribution of water inside the storage tank, solar collector flow rate and its inlet and outlet temperatures as well as load/consumption outlet and inlet temperatures and the corresponding water flow rate under realistic operating conditions. The measurements continued for 120 days during August till November. It was observed that the DSHWS under investigation is able to meet the hot water demand of a four person family for the period mentioned. However, it must be assisted by an auxiliary energy supply like an electrical heater for the rest of the year. In Fig. 4, the typical daily variation of the rate of thermal energy delivered by the collector loop to the storage tank is shown for August till November. It is seen that the heat delivered to the storage tank is rising from 8 a.m. till 13 p.m. after which it starts to decline. The typical daily variation of the collector inlet and outlet temperatures is also shown in Fig. 5. This shows that the collector outflow may reach over 70 °C at around 14 p.m. while its cold inflow temperature is below 40 °C. A similar system is installed in Ardekan city to provide hot water for a public pool. The results of this investigation and the performance of the currently installed DSWHS reveal that these systems are capable

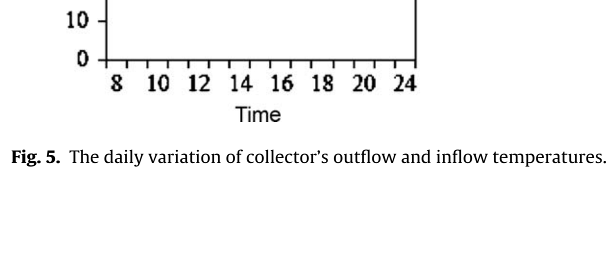


Fig. 5. The daily variation of collector's outflow and inflow temperatures.

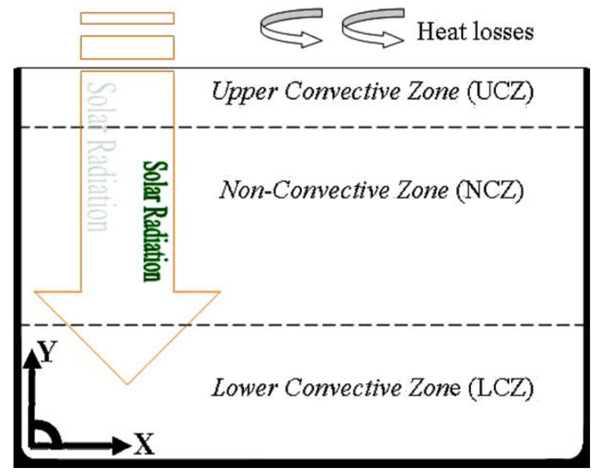


Fig. 6. A schematic diagram of salt gradient solar pond.

enough for providing hot water consumption in houses, schools, commercial buildings, etc. The utilization of such simple and low maintenance cost hot water systems can greatly reduce the utilization of high grade fossil fuel for low grade hot water production.

Solar ponds are another important application of solar energy utilization for hot water production. They are a kind of thermal energy storage systems which are exposed to solar radiation and use water as both absorber and heat storage media. Among various types of solar ponds, salt gradient solar ponds are more popular and less costly to operate. In a salt gradient solar pond, the solar absorber (collector) and the storage section are combined to each other in order to provide hot water for domestic or industrial purposes with the temperatures varying from 70 °C to 90 °C. A salt gradient solar pond consists of three layers; lower convective zone (LCZ) that is uniform in concentration and has the most degree of salinity near the saturated brine, non-convective zone (NCZ) consist of salt gradient and upper convective zone (UCZ) is uniform in concentration too and has the minimum degree of salinity between fresh water and sea water. A schematic diagram of a typical salt gradient solar pond is shown in Fig. 6. No report has been available to indicate the utilization of solar pond to power or heat generation in Iran. However, there are few researches conducted to evaluate the thermal performance of such solar energy conversion systems. The first one is an experimental study, conducted in Birjand, the capital of South Khorasan to evaluate the stability and efficiency of such storage systems [9]. A small solar pond with an exposed area of 1.8 m^2 was built in Birjand and it was seen that the temperature of the bottom layer storage zone reached up to 65 °C. According to the experimental results, it was estimated that a solar pond with an area 1 km^2, could store thermal energy of around 1500 MWh/day. In another experimental work, a small solar pond having 4 m^2 area and 1.1 m depth was built in Mashad, the capital of Khorasan Razavi Province to evaluate its thermal characteristics. The bottom layer NCZ temperature of 51 °C was reported. It was concluded that the NCZ temperature is more influenced by the solar radiation intensity rather than the ambient condition. Few theoretical and experimental studies were carried out to assess the capability and applicability of such low maintenance cost solar storage systems in Yazd Province. The most relevant one is an extensive experimental investigation conducted in Bafgh city to evaluate the thermal characteristics of two small solar ponds with different cross sectional shapes [10]. Two solar ponds with square and circular cross sections, having the same exposed area to the solar irradiation of 3 m^2 and depth of 1.5 m, was built. For thermal performance analysis, 30 thermocouples were installed in each solar pond to monitor the thermal field evolution during the storage period. The

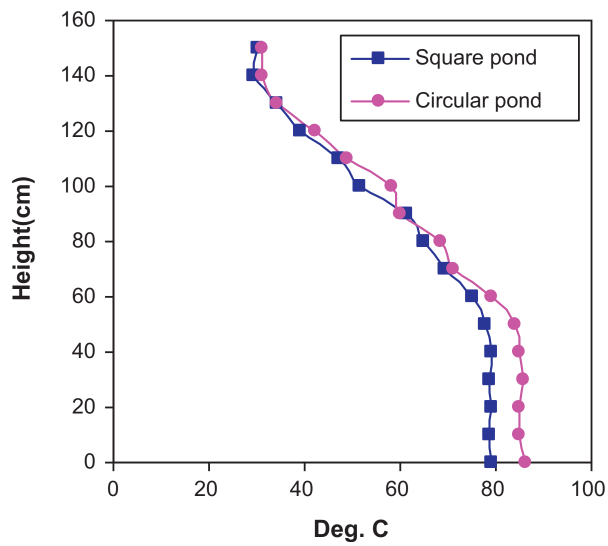


Fig. 7. Temperature profile along the centerline of circular and square experimental solar ponds.

data collection commenced at the 1 January when the temperature inside the ponds was uniform at around 7 °C. Fig. 7 shows the temperature profile along the centerline of both ponds in *Y* direction (Fig. 6) at 1 August. It is seen that a stable thermal stratification is developed inside both ponds as time elapses. The temperature in both UCZ and LCZ are uniform, while it varies almost linearly in the NCZ. This is the feature of a stable salt gradient solar pond. It is also seen that the temperature in the storage LCZ zone may reach as high as 90 °C. In the storage zones of both ponds, heat exchangers were also installed to collect the stored thermal energy. The results of this research indicate that Yazd Province is a very attractive area for employing solar ponds. They can be employed to provide part of the hot water consumption of the industrial zones which are usually located beneath all major urban areas in Yazd Province. The employment of intermediate size solar ponds could greatly help in preserving the high grade fossil fuels for other purposes rather than hot water production. The availability of vast flat lands in Yazd Province facilitates the construction and utilization of such low maintenance cost solar storage systems.

4. Wind potentials

Tentative wind energy map of Iran is recently prepared by the Renewable Energy Organization of Iran. To prepare the wind map, 50 wind velocity measurement stations were installed in the first step, and in the second stage 50 more stations are added. Five of these stations are distributed in Yazd Province. These stations are equipped with all the necessary measurement devices such as hygrometer, pyrometer, and velocity measurement sensors installed at various elevations. The map indicates that there are several locations in Iran which has great potentials for harnessing wind energy for power productions. The wind velocity in these locations may reach up to 12 m/s. There are currently157 installed wind turbines with 89.83 MW capacity in Iran. The wind power generation capacity is expected to reach 100.95 MW by installation of additional 32 wind turbines in Gilan Province in the near future [1]. A detailed statistical survey has been conducted to asses the wind potential as a renewable energy source in major cities of Yazd Province [11]. The wind velocity data at 10 m from ground level is used to estimate the wind velocities at 20 m and 40 m by utilizing a power law correlation. The results of wind velocity for major cities of Yazd Province and for different altitudes are shown in Table 1. It was concluded that Herat region which is located at latitude 30.065N and longitude 54.368E with an altitude of 1600 m above the sea level is the best location for wind turbine installation. However, cities of Aghda, Gariz, Maybod with moderate wind potential are suitable places for small wind turbines installations. In another research work it is stated that wind energy can be feasible where the average wind velocity is higher than 5–6 m/s [12]. Therefore, figures presented in Table 1 reveals that some of the locations in Yazd, especially Herat region is eligible to utilize wind energy. Moreover, the data reveals that wind energy potentials in most locations in Yazd Province are suitable for installing wind driven pumps to assist extracting of underground water for irrigation purposes especially at remote areas with hard access to the electrical grids. Despite good wind potentials of the region, no plans either from government or private sectors are reported to utilize the wind energy potentials of this region. It is hoped that the final results of the wind energy map convince the Ministry of Energy to consider the wind potentials of this province.

Table 1
Annual wind velocity at various altitudes for 2004 [11].

City	V_{10}	V_{20}	V_{40}	V_{max}
Yazd	2.91	3.56	5.35	13.19
Bafgh	2.71	3.77	3.69	12.6
Tabas	1.01	0.36	1.38	11.44
Marvast	3.91	4.48	5.16	15.85
Abarkouh	3.24	3.78	4.40	14.99
Rabat	3.33	3.70	4.10	10.88
Maybod	3.50	3.77	4.75	14.05
Mehriz	3.33	3.41	4.52	11.31
Aghda	3.84	3.72	5.21	16.15
Herat	5.05	5.80	6.66	15.25
Gariz	3.95	4.74	5.66	12.59

5. Summary and conclusion

The present study attempted to review and discuss the status, potentials and opportunities of Yazd Province in harnessing renewable energies and employing their related technologies with an emphasize on solar and wind energies. Being in the sun belt, the province has a great potentials of utilizing promising solar energies technologies. Yazd Province currently is employing a 12 kW off grid PV system for rural area electrification. Besides, a combined steam-gas-solar power generation cycle, which employs parabolic trough solar collectors as a supplementary steam generation, is installed in Yazd city. The gas and steam cycles are under operation now and the solar cycle is anticipated to join the system in 2011. Extensive experimental works are conducted on a domestic solar water heater system (DSWHS) and pilot solar ponds to evaluate their thermal performance in the climate of Yazd Province as a short-term and long-term energy storage systems. It is noticed that the collector outlet temperature of 70 °C and the LCZ temperature of 90 °C is attainable, demonstrating that these low cost solar based systems are viable and reliable means of supplementary thermal energy generation. Wind velocity data reveals that this region is capable of utilizing wind energy for both driving small wind turbines and wind driven pumps for farmland irrigation. Despite the high potential of the region on utilizing the various sources of renewable energies, the employment of renewable energy technologies are premature due to the availability of highly subsidized electricity and fossil fuels. However, due to the desubsidization scheme to be implemented to the energy commodities, the utilization of renewable sources of energy is an inevitable challenge for the region. Therefore, the local government is responsible to provide enough motivation and incentives among the various energy users' sector and present adequate demonstration and justification of renewable

energy technologies. This ensures that sufficient energy is available for sustainable development of Yazd Province.

References

[1] Word energy scenario, Iran Energy Balance Report. Iran's Ministry of Energy; 2008.
[2] Fadai D. Utilization of renewable energy sources for power generation in Iran. Renewable & Sustainable Energy Reviews 2007;11:173–81.
[3] Mostafaeipour A, Mostafaeipour N. Renewable energy issues and electricity production in Middle East compared with Iran. Renewable & Sustainable Energy Reviews 2009;13:1641–5.
[4] Safaii B, Khalaji Asadi M, Taghizadeh H, Jilavi A, Taleghani G, Danesh M. Estimating solar energy potentials in Iran and related radiation atlas. Journal of Nuclear Science and Technology 2005;33:27–34.
[5] Chaurey A, Kandpal TC. Assessment and evaluation of PV based decentralized rural electrification: an overview. Renewable & Sustainable Energy Reviews 2010;14:2266–78.
[6] http://solar_4_you.com.
[7] Ramos JS, Ramos HM. Solar powered pumps to supply water for rural or isolated zones: a case study. Energy for Sustainable Development 2009;13:151–8.
[8] Dehghan AA, Hosni MH, Shiryazdi SH. Experimental evaluation of the thermal behavior of a vertical solar tank using energy and exergy analysis. In: Proceedings of IMECE2005, ASME international mechanical engineering congress and exposition; 2005.
[9] Bidokhti AA, Mohammadnejad AR. Stability and efficiency of a small solar pond. Esteghlal Journal 1998;16(1):67–75.
[10] Mazidi M, Dehghan AA. Salt gradient solar pond, Research Report. Iran: Islamic Azad University-Bafgh Branch; 2009.
[11] Mostafaeipour A. Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. Renewable & Sustainable Energy Reviews 2010;14:93–111.
[12] Himiri Y, Malik AS, Stambouli AB, Himri S, Draoui B. Review and use of the Algerian renewable energy for sustainable development. Renewable & Sustainable Energy Reviews 2009;13:1584–91.